An Experimental Assessment of Stabilised Rammed Earth Block in Unreinforced and Reinforced conditions

Synopsis

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Submitted by

Randeep

Under the supervision of

Prof. V. Soami Das

Professor, Department of Civil Engineering

Department of Civil Engineering, Faculty of Engineering

Dayalbagh Educational Institute, (Deemed to be University)

Dayalbagh, Agra-282005

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1.1 Introduction

The term rammed earth describes a building technique in which earth (clay, silt, sand, and gravel) is the primary constituent, compressed within a framework to offer the desired shape, with or without a stabilizing agent as per the required strength. It is an ancient sustainable building method that has been revived recently. Making rammed earth involves compacting a damp mixture of subsoil. Rammed earth blocks differ from mud bricks, as the mud bricks are not compressed and harden through chemical changes that take place as they air dry. The compression strength of accurately made rammed earth block is usually higher than that of typical mud brick. Many of the inadequacies associated with the durability of rammed earth (mainly external surface protection, water resistance, shrinkage, and strength) can be averted by the addition of a stabilizing material. Historically, additives like lime and cement were used to stabilize it. The compressive strength of rammed earth increases with the curing and it depends on soil type, particle size distribution, compaction energy, moisture content, and type/quantity of stabilizer used. Due to its high thermal mass, the energy input required in rammed earth extraction, production, and transportation is inherently low, hence, it has been established as environmentally sustainable. Recently rammed earth construction is regaining popularity because of its sustainable and energy-efficient nature. The strength (compressive and flexure strength), durability, ductility, and shrinkage cracks in unstabilized rammed earth can be enhanced by stabilizing with some additives and reinforcing with natural and artificial fibers.

1.2 Motivation and Significance

With the global population growth and demand for urbanization, the demand for valuable natural resources has consistently increased all over the world which causes ecological unbalance (resources exploitation) that is responsible for global warming as shown in the figure. According to Edwards (2005), 50% of the natural resources are consumed in the construction sector across the planet, making it one of the least sustainable industries in the world. The study shows that building construction is responsible for one-sixth of the world's freshwater extraction, one-quarter of wood harvesting, and two-fifths of material and energy requirements resulting in numerous side effects on the entire natural world and its existence (Roodman et al. 1995). Indiscriminate use of natural resources and energy-intensive processes for the building materials will not lead to sustainable options. If the entire world

continues this act of global warming and climate change to occur, then the time is not so far when the existence on the earth will be difficult. Buildings being, an active participator in the environmental deterioration process, there is a need for urgent alternate solutions to current practices which fulfill the criteria of sustainability and structural stability. Using these energy-intensive materials like cement, concrete, and steel in construction, the outside temperature is higher mainly in the summer season, the outer heat is transferred to the interior of a building through conduction from the walls and roof. The thermal conductivity of conventional materials of construction (e.g., concrete, stone, and steel) is high enough to absorb the exterior heat and transfer it to the interior of a building well before this duration. The interior heat of a building is so high that it is not affected by any drop in the outside temperature during the night. Therefore, the buildings constructed using traditional materials of construction need air conditioning even at night, which consumes too much energy Zardari et al. (2018). IPCC 2007 mentioned that to stabilize this rapid growth of climate change in totality, emissions need to be reduced by 70% globally. In the context of carbon emission reductions and the issues of global warming, there is a need to pay attention to the use of modern building materials with reference to (i) energy intensity of materials, (ii) natural resources and raw materials consumed, (iii) recycling and safe disposal and (iv) impact on the environment.

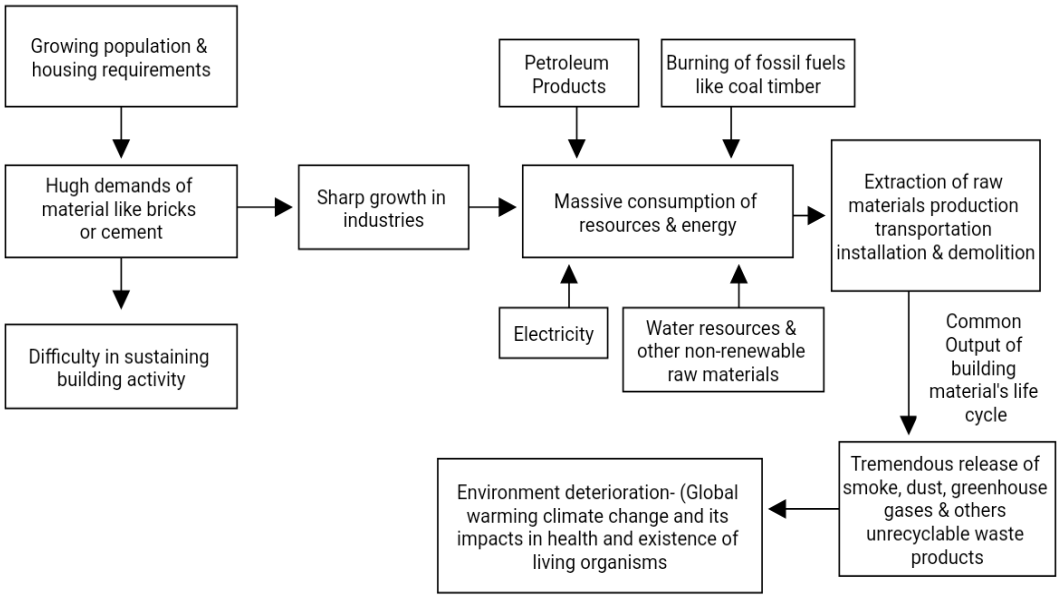
Growing population & housing requirements
Petroleum Products
Burning of fossil fuels like coal timber
Hugh demands of material like bricks or cement
Sharp growth in industries
Massive consumption of resources & energy
Extraction of raw materials production transportation installation & demolition
Difficulty in sustaining building activity
Electricity
Water resources & other non-renewable raw materials
Common Output of building material's life cycle
Tremendous release of smoke, dust, greenhouse gases & others unrecyclable waste products
Environment deterioration- (Global warming climate change and its impacts in health and existence of living organisms

Figure: Environmental impacts due to Growing population and their housing demand (Khadka B., 2019)

1.3 Hypothesis

Realizing that the sustainable material production, construction, maintenance, and re-use of building materials can play a vital role in reducing environmental impacts. One of the natural and historical materials, i.e., soil in the form of rammed earth has the maximum potential against all the concerned issues. However, when the rammed earth technique is to be applied in new constructions, its physical (particle size distribution and mix proportion) and mechanical performance (density and strength) are frequently not good enough to reach the values defined by the building standards. To improve these physical and mechanical properties, and some other aspects such as the thermal and acoustic behavior, diverse additives, like cement and lime can be added to the earth and water mixture, leading to the so-called stabilized rammed earth. (Khadka and Shakya 2016, Hall et al. 2012). For the sustainability of earth structures, it is necessary to define a stabilized reinforcement system that is to be eco-friendly. According to information collected from the literature, vegetal fibers, for example, broom, flax, hemp, jute fibers, or fibers taken from bamboo, pineapple, and coconut, exhibit the necessary strength and adhesion properties to act as a reinforcement of masonry material. The economic and environmental concerns of conventional building materials have created the need to explore alternative materials which are less energy-intensive and cost-efficient and at the same time satisfy the strength and safety criteria too. In line with this attempt and a step forward in sustainable development, a comprehensive experimental investigation is to be done to assess the feasibility of using earth blocks for construction purposes. The motive of this study is to provide sustainable construction solutions for affordable housing worldwide which promote more sustainable alternatives to other conventional modern construction techniques. An additional potential benefit of this study could be the improvement of the living conditions for low-income, under-represented, and under-served populations around the world, both in developing and developed countries.

1.4 Scope of work

There are several historical rammed earth structures around the world and their strong evidence is available in the Great Wall of China or in the Alhambra (Spain). The scope of this study is to use the locally available soil for rammed earth which can be sourced on-site at zero or almost zero cost. Processes concerned with the production of rammed earth blocks are less energy-intensive than the

cement and burnt brick manufacturing processes. It means, soil blocks have less impact on the environment and are more sustainable.

The proposed work is a state of the art of rammed earth blocks in unreinforced and reinforced conditions, aims to investigate the different composite options with limestone dust powder and limestone calcined clay cement (LC^3) as binders and pine fibers and jute fibers as a reinforcing material. The above-mentioned reinforcing materials are natural and have a negligible environmental impact and the same with the binders with reference to their particular use. There is a large scope for utilizing sustainable binders and natural fibers in building construction for promoting sustainable construction practices.

1.5 Materials

1.5.1 Soil

Locally available low plastic raw soil having low organic content is to be used for the proposed work with a definite proportion of clay, silt, sand, and gravel. Moreover, the soil is locally available, and its abundance makes it an easy-going and affordable construction material, specifically for large-scale housing in rural areas of less economically developed countries.

1.5.2 Binding Material

Limestone dust is a waste material that is slightly coarser than common cementing materials such as Portland cement and coal fly ash. It has the potential to act as Supplementary Cementitious Materials (SCMs) depending on the percentage replacement and chemical composition of the dust. Another binder is LC^3, an innovative blended Portland cement that is based on a blend of limestone and calcined clay. The main components of LC^3 are clinker, calcined clay, limestone, and gypsum.

1.5.3 Reinforcing Material

To enhance the soil matrix property and for durability analysis, pine needles and jute fibers are proposed for this research work. Pine fibers or needles are renewable and have a low utilization rate, so they have the potential to be developed into natural plant fiber materials. The area which comprises a large pine forest is vulnerable to fire during every summer season. Therefore, to minimize negative impacts like harmful emissions after the fire, fibers of Pinus Roxburghii have been proposed as a reinforcing material for rammed earth block to advantageously use this forest waste product. Jute is

also a natural biodegradable long, soft, shiny bast fiber obtained by retting the jute plant stem which has good tensile strength and thermal properties. The use of natural fibers as reinforcing material reduces carbon emissions and gives better thermal insulation properties.

1.6 Rammed Earth

The increasing trend of the population in developing countries world will continue to face a housing deficit challenge. In terms of construction materials, the steel, and cement industries produce approximately 12% of global CO_2 anthropogenic emissions, which is the largest percentage among construction materials (Huang et al. 2017). The lack of economic resources, the fast-growing rate of carbon emissions, and the demand for construction materials like steel and cement, pressurize the governments to find alternative solutions to the above-mentioned housing deficit problem. Numerous civilizations have used raw earth which represents a sustainable construction practice because of its low cost, local availability, and recyclability, but also because it allows satisfying environmental comfort, and thermal and acoustic insulation of the interior, with minimum energy. Among other common earth construction, rammed earth is consuming less energy. Venkatarama Reddy (2009) showed that the use of alternative low-energy building technologies results in about a 50% reduction of the embodied energy of a building system. Khadka B (2019) used clay and black cotton soil with silt and gravel. By using cement and dung as a stabilizer, results show that 5% cement-stabilized rammed earth is better compared to dung-stabilized and un-stabilized samples. Among four categories of the sample, un-stabilized rammed earth was quite difficult to handle due to a lack of stabilizer. Similarly, water content above 12% in mix proportion showed problems in workability (during compaction) followed by low strength. Although clayey and black cotton soil followed the same mix proportion and cement content, compressive strength was higher in clay mixed samples. Raavi and Tripura (2020) used coir of 1% to 5% and 25 mm to 50 mm in length as reinforcement and 10% of cement as a stabilizer. CSRE blocks attained higher compressive and tensile strength by about 54.50% and 85.58% respectively as compared to USRE blocks. The investigation shows that the characteristic dry compressive strength increases up to 1% coir of 25 mm length and gradually decreases with the increase in coir percentage and length. However, tensile strength increases with the increase in coir percentage and length. CSRE blocks meet the durability criteria also. Cement stabilization reduces the

microstructure porosity of the material thereby improving the strength and durability properties. The optimum percentage and length of coir for CSRE blocks are found to be 1% and 25 mm in length. Coir reinforcement along with cement stabilization increases the efficiency of rammed earth samples in terms of their ductility, compressive and tensile strength. Rathore and Reddy (2021) characterized the strength and stress-strain behavior of CSRE reinforced with coir fiber. The compressive strength of fiber reinforced CSRE increased by 10-30% for 1% coir fibers. The strain at peak stress and the failure strains have significantly increased with the addition of fibers indicating the improved ductility and the post-peak response of the material. The energy absorption capacity of CSRE increased by 2–5 times for an increase in the fiber volume fraction from 0 to 2%. The sudden catastrophic shear failures observed in the cement stabilized rammed earth under compression can be eliminated by the addition of short randomly oriented coir fibers. The fiber volume fraction of 1% is the optimum. Guettatfi L et al. (2021) used white cement, quick lime, and date palm leaves as fiber to check the durability and mechanical properties of adobe. Due to the addition of quicklime and cement in adobes, density increases, while the addition of palm date fibers decreased the density. The capillarity water absorption was reduced by the addition of stabilizers, but it is also observed that the mixtures containing cement showed higher water absorption values compared to those with quicklime. Cement and quicklime give good results in compressive strength, tensile strength, as well as erosion control but date palm negatively affects water absorption and erosion control but shows some enhancement in compressive and tensile strength. Naeini et al. (2021) used a low carbon sustainable cementing material pulp fly ash with cement and bentonite for rammed earth and concluded a significant increase in compressive strength at 28 days of curing and retained 92% strength after 12 freeze-thaw cycles. Taufigh V et al. (2021) used fly ash and granulated blast furnace slag (GBFS) for stabilization of rammed earth material and concluded that the stress-strain response of material became more brittle as the GBFS to binder ratio increased. The increase in the GBFS to binder ratio led to a dense matrix compared to the fly ash matrix. Kumar and Barbato (2022) used sugarcane bagasse fibers (0%, 0.5%, and 1%) in cement (0%, 6%, and 12%) stabilized earth blocks and concluded that the compressive strength, modulus of rupture, and the flexural modulus of elasticity of CSEBs improved with increasing cement content and sugarcane bagasse fibers. Stabilization is necessary because

unstabilized blocks are not able to survive the wet compression test nor the wetting and drying cycles of the durability test.

1.7 Limestone Dust Powder & Limestone Calcined Clay Cement (LC^3)

Large quantities of industrial by-product residues are generated all over the world, owing to the rapid industrialization growth. The accumulation of these wastes presents considerable environmental and economic problems, especially considering the limited available landfill facilities. There are many ongoing research activities into the possibilities of recycling and reusing waste materials in highway or building construction, partly as a solution to the pollution problem associated with waste disposal and as a means of cutting back project costs attributable to the high cost of extracting virgin or natural construction materials. To meet the demand for new constructions and to sustain the construction activity, it becomes inevitable to explore the use of industrial/mine solid wastes for the manufacture of building materials. Such wastes can be utilized for the manufacture of bricks/blocks, substitute as a building material, and partial replacement of binding material can be done. In recent years, some research has been done to study the effect of using alternative binders such as ground granulated blast furnace slag, fly ash, rice husk ash, bagasse ash, cement kiln dust construction, and demolition waste along with cement and lime in the concrete, mortar, and soil. All these binders have shown a very positive contribution. The type of available industrial waste depends on the kind of industrial activity in an area or country. Therefore, limestone dust, a waste product, and Limestone Calcined Clay Cement (LC^3) is proposed for this study to know the effect of their addition on rammed earth. Some work has also been done to investigate the potential of the limestone dust powder for being used as a binder for concrete and soil improvement which gives promising results. Literature shows that limestone dust powder is used as a filler material for cement or aggregates and has some beneficial effects on concrete. So, it has the potential to act as Supplementary Cementitious Materials (SCMs) depending on the percentage replacement and chemical composition of the dust. LC^3 is an innovative blended cement that is based on limestone and calcined clay. The main components of LC^3 are clinker, calcined clay, limestone, and gypsum. Calcined clay and limestone are already commonly used as SCMs. The additional alumina in the metakaolin reacts with the ground limestone, leading to a less porous material, and therefore providing equal strength with higher levels of clinker substitution.

Prakasan et al. (2019) stated that the energy use and CO_2 emissions of PPC are at least 20% less compared to OPC and LC^3 saves up to 40% of CO_2 as compared to Ordinary Portland Cement that including the addition of metakaolin (calcined kaolinite clay) and limestone. Most of the CO_2 comes from the clinkerisation (temperatures between 1400 and 1500°C) process. Therefore, reducing the clinker factor and replacing it with SCMs is the fastest intervention to save high numbers of CO_2. Gettu et al. (2019) also mentioned that limestone calcined clay cement shows considerable promise in terms of reduction in CO_2 emissions and energy demand in both cement and concrete. Utilization of lower grade material for LC^3 like clay waste and limestone waste (dolomite presence) proves an economical and sustainable solution that solves the disposal problem as well. The raw materials limestone and calcined clay are abundantly available worldwide. Other commonly used Supplementary Cementitious Materials like fly ash or slag are already fully used and cannot be scaled for use in cement. Furthermore, with an increasing focus on sustainability more and more coal power and steel production plants are expected to be closed. This will further cut the supply of these materials as SCMs. The only material largely available worldwide and in sufficient quantity are kaolinitic clays and limestone. Overall, the production cost can be up to 25% lower for LC^3 than for OPC due to savings in energy and material.

1.7.1 Brief Review of Literature on Limestone Dust Powder and LC^3

Brooks et al (2011) used fly ash and lime dust to stabilize the geotechnical properties of soil and stated that both fly ash and lime dust have the potential as a stabilizing material that has significantly enhanced the soil properties. Torkaman et al (2014) used wood fiber waste, rice husk ash, and limestone powder waste as cement replacement in lightweight concrete and concluded that composites containing LPW had superior compressive strength compared to the other studied composites. Limestone powder waste is effective in reducing the bulk density without a considerable negative effect on the compressive strength and limestone powder waste has the potential to be used in the production of a new lighter concrete block and to be used as an alternative to the ceiling panels, sound barrier panels, absorption materials, etc. Pastor et al. (2019) studied the effect of the addition of limestone powder to clayey soil on unconfined compressive strength, compressibility, and

microstructure and concluded that UCS increases, compressibility decreases, and SEM show a more compacted microstructure.

The cement industry is one of the highly energy-intensive sectors in India with an annual energy consumption of 15.01 million tons of oil equivalent, (Ministry of Power 2015). The annual greenhouse gas emissions (GHG) of the cement industry are about 129 MT in the year 2007, which is 6% of the total GHG emission and 32% of the total CO_2 emissions from the industrial sector in India, Midha et al. (2015). The conventional supplementary cementing materials (SCM), including fly ash, blast-furnace slag, and silica fume, may not be available everywhere for continued long-term usage. Finding alternative SCMs appears to be an urgent issue to ensure the uninterrupted use of sustainable cementitious materials. Compared to the common SCMs, limestone, and (calcined) clay stand out as ideal raw material candidates that are largely abundant worldwide, Scrivener K et al (2018). Berriel et al. (2016) stated both an economic and environmental aspect and showed that the LC^3 technology, which involves the combination of 50% of clinker, 15% of unburned limestone, and 30% of calcined clay (and 5% Gypsum), was energy and cost-efficient technology. Savings in terms of greenhouse gas emissions, as well as production and investment costs, were significant. LC^3 had therefore great potential to provide a viable opportunity to meet an increase in cement demand with low CO_2 released. Diaz et al. (2017) mentioned that LC^3 represents a grounded alternative against a very fast increase in demand due to the population as well as economic rise, and a need to mitigate greenhouse gas emissions. Shah et al. (2018) replaced cement with limestone calcined clay pozzolan and concluded that it affects positively the early age hydration of cement. Higher or similar compressive strength was observed for all the LCCP blends as compared to ordinary Portland cement. The pozzolanic reaction of calcined clay aids in reducing transport properties of concrete such as porosity, rate of water absorption, and permeability. Dhandapani et al. (2018) describes the potential of Limestone Calcined Clay Cement (LC^3) for use in structural concrete in comparison with Ordinary Portland Cement (OPC) and fly ash-based blended cement. The results indicate the superiority of the LC^3 binder over other binders in producing durable concrete. The major reason for the better performance was attributed to the more compact and denser microstructure of the system with the LC^3 binder against OPC and fly ash. Baghban and Mahjoub (2020) concluded the Combination of LC^3 with natural fibers such as

kenaf fiber can be a promising composition to get green concrete with low GHG emission and energy consumption due to the replacement of cement by LC^3. Mechanical properties of concrete such as toughness, tensile strength, and impact resistance can be improved by using kenaf fiber but durability properties such as carbonation, sulfate, and chloride resistance were reported to be enhanced by LC^3 as compared to OPC concrete. Reddy et al.(2021) compared the Limestone Calcined Clay Cement (LC^3) based concrete with Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC) based concrete and concluded that replacement of clinker with LC^3-50% is beneficial in terms of strength and durability. Although the addition of limestone powder to local soil for rammed earth block production gives some additional sustainable benefits to the environment, both by avoiding the use of traditional binders, which have a strong environmental effect on its manufacturing process and by avoiding dumping the waste from the industry into landfills. Literature shows that very limited studies have been undertaken on the use of limestone dust in combination with LC^3 for rammed earth blocks. There is still a huge gap that is to be researched to better understand the effects of limestone dust powder and LC^3 on rammed earth block production.

1.8 Pine Fibers

To meet the requirements of energy savings, green environmental protection, and sustainable development in engineering construction, the use of natural biomasses as raw materials for engineering construction has become a focus of research in recent years. Pinaceae plants are widely distributed worldwide. A pine, locally known as Chir pine, (Pinus roxburghii), is a coniferous tree that is native to the Himalayas. The softwood fiber of the pine is the main raw material used in the papermaking, fiberboard, and particleboard industries. However, there are few applications in which to use the large quantity of the remaining pine needles. Pine fibers or needles are green and bundled in clusters called fascicles. The leaves (pine needles) are renewable, numerous, and have a low utilization rate, and they have the potential to be developed into natural plant fiber materials. The use of natural fibers as reinforcing material reduces carbon emissions and protects the green environment.

1.8.1 Pine Fibers as Reinforcement

Some studies pointed out that the use of untreated natural fibers in cement or concrete slurries is ineffective unless the fibers are treated to remove organic impurities. It was evident that if the fibers

are used without treatment, the bond in the cement matrix would be weak and not effective, Awwad E. et al. (2012). Sharma V. et al. (2016) worked on the durability and strength of adobe blocks by the addition of natural reinforcement of Grewia Optiva and Pinus Roxburghii. In the wetting and drying test, 1% Pinus Roxburghii with 2.5% cement showed a good improvement in durability as well as strength. Finally, 1% Pinus Roxburghii and 2% Grewia Optiva are recommended for sustainable stabilization to avoid regular maintenance problems. Sandoval et.al. (2018) used wheat straw fibers along with three varieties (Pinus halepensis (pn1), Pinus pinea (pn2), and Pinus pinaster (pn3) of pine needles as natural reinforcement and concluded that pine needles can be used for adobe manufacturing because of their higher resistance. Pinus halepensis (pn1) give higher ductility to the adobe because of its lower modulus of elasticity. Long W and Wand Y (2021) select Masson pine needle fiber (MPNF) to study the influence of this plant fiber on the mechanical properties of concrete, demonstrates the feasibility of adding MPNF to concrete by performing compressive, splitting tensile, and modulus of rupture test and concluded that alkali treatment and boiling water treatment exhibited improved compressive strength and splitting tensile strength results as compared to soaked treatment with 1% of MPNF content. Resin present in the pine needle will slow the cement hydration. Mustafa Tolga Cogurcu (2022) investigate the use of red pine needle fiber in high-performance concrete and concluded that a decrease in slump, an increase in compressive strength, and flexural strength significantly.

1.9 Jute Fibers

Jute is a long, soft, shiny bast fiber that can be spun into coarse, strong threads. Jute is one of the most affordable natural fibers, and second only to cotton in the amount produced and variety of uses. Jute fiber obtained by retting the jute plant stem, contains three main categories of chemical compounds: cellulose (58-63%), hemicellulose (20-24%), and lignin (12-15%). Approximately one thousand varieties of jute have been identified by the raw jute division of the Indian Jute Institute Research Association (IJIRA), Calcutta, Gowda TM et al. (1999). Thus, one has very little control over the properties and characteristics of jute fabric as it arrives on the market. The retting process also influences the strength and the colour which can vary from brown to white. Jute yarns are obtained by the simple spinning of jute fibers. Jute fibers are roughly interlocked in yarns connected to one another

by friction, producing a new material whose properties are clearly lower than the properties of single fibers, and sensitive to the yarn length. Jute fabric is a textile made of plain weaving of jute yarns.

1.9.1 Jute Fibers as Reinforcement

Jute is a natural biodegradable fiber characterized by good tensile strength and good thermal conductivity which is abundantly grown in Bangladesh, China, India, and Thailand. Recently, due to the improvement in people's living standards and the need for environmental protection, the demand for natural biodegradable and eco-friendly fibers is rising worldwide. Hejazi et al. (2012), reported that jute as an environmental-friendly fiber could be used for soil stabilization in pavement engineering. The use of jute fibers as reinforcement of the earth has been mostly related to the stabilization of soils. Singh and Bagra (2013) conducted an experimental study on locally available soil reinforced with jute fiber. The soil samples were prepared at their MDD and OMC in the CBR mould with 0.25%, 0.5%, 0.75%, and 1% jute fiber and without reinforcement. Tests result indicates that the CBR value of soil increases with the increase in fiber percentage. It was also observed that increasing the length and diameter of fiber further increases the CBR value of reinforced soil. Gullu and Khudir (2014) analyzed the effect of freeze-thaw cycles on unconfined compressive strength (UCS) of fine-grained soil (low-plasticity silt) treated with jute fiber, steel fiber, and lime. The results show a significant increase in UCS with the 4% lime + 075% jute fiber + 0.25% steel fiber combination. The stress-strain responses after the inclusions due to the jute fiber alone in terms of post-peak strength, strain hardening, and ductility are better than the ones of steel fiber and lime at all freeze-thaw cycles. Loccarini F. et al (2016) demonstrated that jute fabric applied with a stabilized earth plaster as a reinforcement system for earthen structures that develop exceptional adhesion and adequate stiffness. Sujatha and Devi (2018) mentioned that jute fiber reinforcement has shown the highest resistance to abrasion and erosion among glass, polypropylene, and banana fiber. Letelier et al (2021) evaluated the effectiveness of jute fibers with different dosages and varying lengths as fiber reinforcement of adobe mixtures and concluded that an increase in capillary water absorption affects its durability, but this occurs at a higher dose (e.g., 2%). The incorporation of jute fibers clearly improved cracking control by reducing both crack width averages and crack density ratios. Erosion due to water is significantly mitigated by the addition of jute fibers. Vincenzini et al. (2021) mentioned

the use of both natural and synthetic fibers and additives such as cement, lime, and ash and found that the use of natural fibers performs better than synthetic. Specifically, jute fibers achieved the best adhesion with the soil mix.

1.10 Concluding Remark and Research Gap:

It is extremely difficult to sustain the construction activity to meet up the future requirement for infrastructure using the currently available energy-intensive materials and technologies. The use of compressed rammed earth blocks in the stabilized and reinforced condition is deemed satisfactory and sustainable over the other modern construction materials like burnt bricks, cement, steel, etc. The literature clearly shows that the rammed earth blocks are more eco-friendly, i.e. their manufacturing consumes less energy and pollutes less compared to fire bricks and concrete blocks. Developing such green home construction techniques can be a major step toward reducing the building's carbon footprint and saving the planet from the consequences of resource scarcity, global warming, and climate change.

Despite their several benefits, rammed earth suffers from lesser resistance to cracks and erosion as well as lower mechanical strength. To enhance the above-mentioned properties, the literature clearly stated that some cementitious and reinforcing materials are used.

Cement and lime were used historically but cement (OPC) itself is the most unsustainable material. Due to the competency of pine needles and jute fibers in soil reinforcement and concrete as proven by the literature, utilization as reinforcing materials seems promising. But the effect of pine needles and jute fibers as reinforcement for rammed earth blocks has never been evaluated before. Therefore, the potential use of binders (e.g., limestone waste powder and LC^3) and natural fibers (pine fibers and jute fibers) in rammed earth composites has been explored very limited which raises the interest of research with the following research gap:

- First, it is required to perform a detailed and systematic study of rammed earth and its engineering properties.
- Need to address certain issues concerning the energy requirement, carbon emissions, and sustainability of the building construction practices.

- Primarily use of environmentally sustainable binder (e.g., limestone waste powder and LC^3) which has the potential to limit the use of highly energy-intensive cement, and their effect on physical and mechanical properties of rammed earth block have not been discussed yet in detail.
- At present, the potential use of limestone calcined clay cement (LC^3) with natural fibers like pine and jute fibers in rammed earth composites has not been explored.
- Effect of addition of concerning additives individually and in composite on UCS with different curing periods is to be studied.
- Stabilised earth blocks show sudden catastrophic shear failure, due to the addition of natural fibers, its stress-strain analysis and ductility behavior has not been exhaustively investigated.
- Still a lot of effort needs to be put on to explore the commercial use of the natural fiber composites.
- The long-term durability of pine and jute fiber-reinforced composites needs to be explored for better insight and effectiveness in civil engineering construction.
- Lesser durability and lower compressive strength have been seen as very prominent factors affecting the use of the earth.
- Shrinkage crack propagation on rammed earth surfaces is not discovered much.
- Fiber and soil interaction are not explored as well as thermal insulation properties of jute fiber reinforcement are discussed in concrete but not in the rammed earth.
- Need to find some sustainable natural reinforcing fiber that is to be cost-efficient, eco-friendly as well as easy to procure and use.

1.11 Objectives

With the consideration of the above-mentioned issues, the present research study is commenced to achieve the following objectives:

1. To examine the binders (limestone dust powder and LC^3) and fibers (pine and jute) effect individually and in composite with different curing periods on the strength and density of rammed earth blocks.

2. Check for possible improvement in strength and durability of reinforced rammed earth blocks with natural fibers of pine and jute compared with the raw soil.

3. To examine the crystalline phase composition, surface morphology, and microstructure by X-Ray diffraction (XRD) and Scanning Electron Microscopy (SEM) analysis.

4. To provide sustainable use of pine fibers (forest waste product), and limestone dust powder (industry by-product) which poses the disposal problems with LC^3 and jute fibers composite in the construction sector.

1.12 Methodology

Limestone dust powder and LC^3 as binders and pine needle and jute fibers are proposed in this work for detailed laboratory investigation to provide the possible comparison, looking at physical and mechanical properties and hydraulic performance as well as durability. For this, a comprehensive set of laboratory tests, namely water content measurement (IS 2720 Part-II), specific gravity (IS 2720 Part-III), particle size distribution (IS 2720 Part-IV), consistency limits (IS 2720 Part-V), soil classification (IS 1498-1970) standard compaction (IS 2720 Part-VII), Unconfined Compressive Strength (IS 2720 Part X), Split Tensile Strength (STS), and Flexural Bending Strength (FBS), permeability, SEM, XRD tests is to be conducted on the concerned composite specimens.

Physical properties i.e., the dry density of the reinforced and unreinforced soil blocks, water absorption through capillarity, and shrinkage are to be determined to evaluate the effect of type and the amount of reinforcing fibers on the soil block's performance.

Mechanical properties are to be evaluated to know the performance of the soil blocks under different loading conditions by performing compressive strength, tensile strength, modulus of rupture, bond strength, and ductility tests under this section.

Durability properties of a rammed earth block can be determined with the help of the wet-to-dry strength ratio and erosion test. The resistance of the rammed earth blocks to severe environmental conditions plays an important role which determining its use as a construction material.

1.13 Work plan

Activity	Time Period (months)					
	1-6	7-12	13-18	19-24	25-30	31-36
Literature Review						
Experimental Investigation						
Analysis and Result Interpretation						
Thesis writing						

1.14 References

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